Global and Seasonal Variations in Gravity Wave Momentum Fluxes: A Comparison of Satellite Observations and Climate Models

M. Joan Alexander, NWRA, Boulder, CO

- **Observations:** HIRDLS and SABER limb-scanners
- **Models:**
  - Traditional climate models with parameterized gravity waves
  - Experimental high-resolution climate models
- *Results are summarized in Geller et al. [2012] (submitted to J. Climate)*

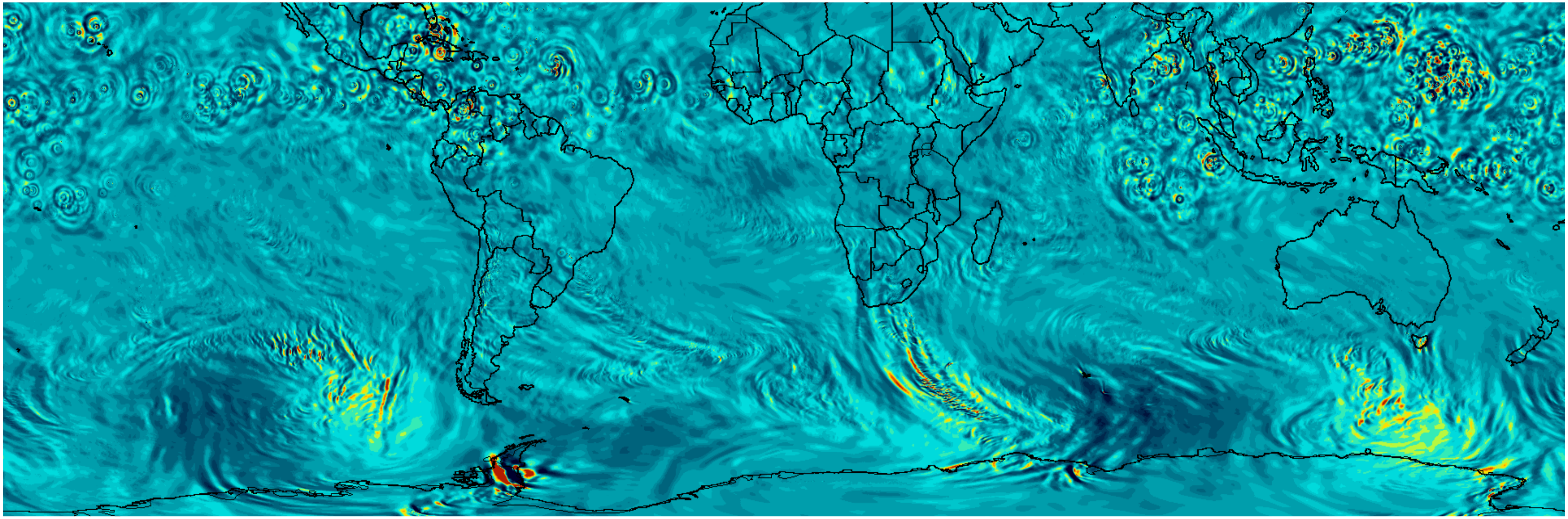
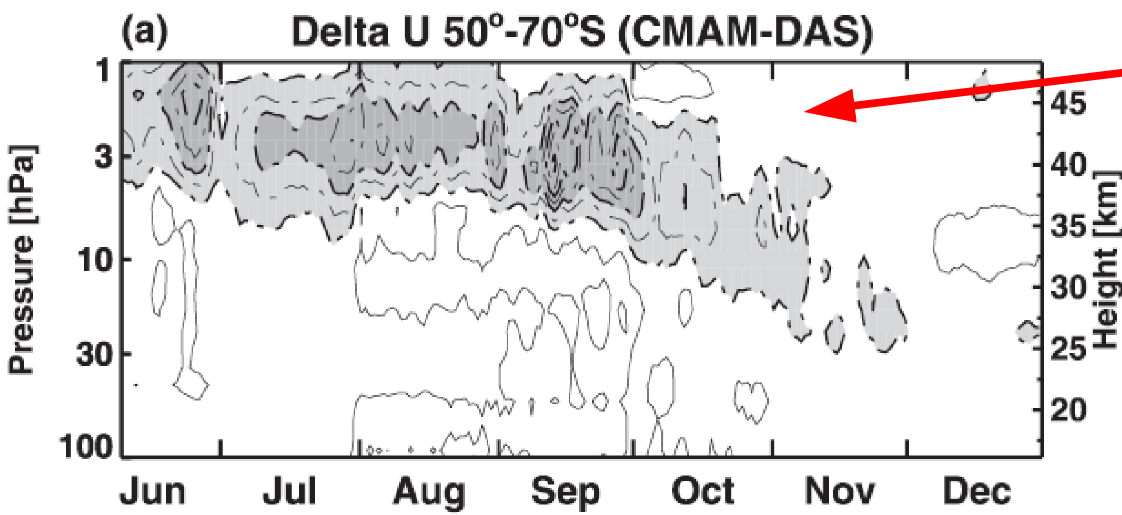


Image courtesy of William Putman

Role of Gravity Wave Drag on Stratospheric Winds and Climate

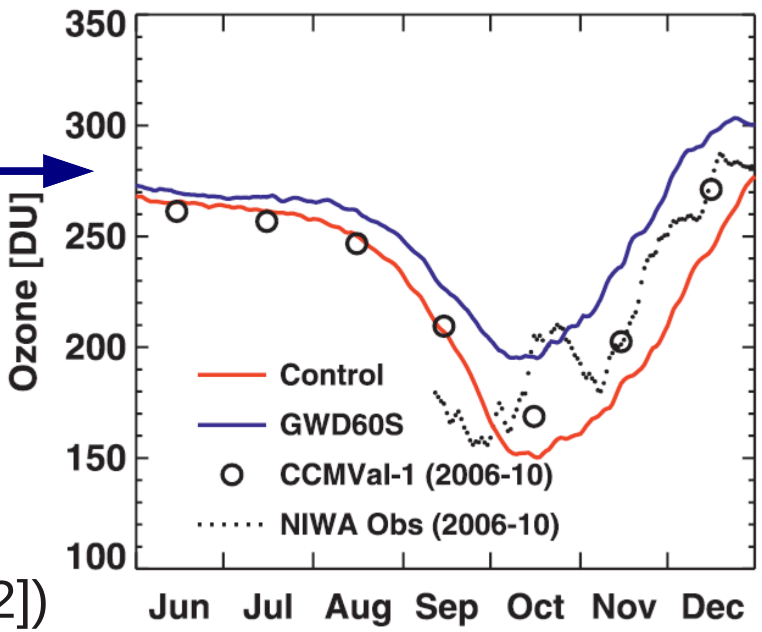
- **Southern Hemisphere stratospheric wind biases are common in climate models** (See Butchart et al. [2011])

Example from McLandress et al. [2012]



Data assimilation zonal wind increments in CMAM-DAS are up to -5 m/s/day (a large fraction >1/2 of resolved wave drag at these latitudes).

Correction of these wind biases with parameterized gravity wave drag gives large changes in the seasonal evolution of stratospheric temperature and ozone.



- **Stratospheric ozone loss and recovery is a major controlling factor of SH climate change** (See e.g. Perlwitz et al. [2008], Gerber et al. [2012])

Can we use satellite observations to test and improve gravity wave parameterizations and climate models?

A First Effort: **An international collaboration funded by ISSI and SPARC to intercompare global measures of gravity wave momentum flux from satellite and balloon observations to gravity waves in climate models.**

The team had two meetings in 2010 and 2011, and submitted a first publication in 2012:

Geller, M.A., M.J. Alexander, P.T. Love, J. Bacmeister, M. Ern, A. Hertzog, E. Manzini, P. Preusse, K. Sato, A.A. Scaife, and T. Zhou: A comparison between gravity wave momentum fluxes in observations and climate models, J. Climate, (submitted) 2012.

See also http://www.issibern.ch/teams/gravitywave/index.html

Gravity Wave Effects on Circulation

Momentum flux (F_M) is a key parameter:

F_M is constant in the absence of dissipation/breaking.

$$\varepsilon \, dF_M / dz = -\rho \times \text{(Force on the Circulation)}$$

ε is a tuning parameter (intermittency); ρ is density.

Momentum Flux from Satellite Temperature Observations

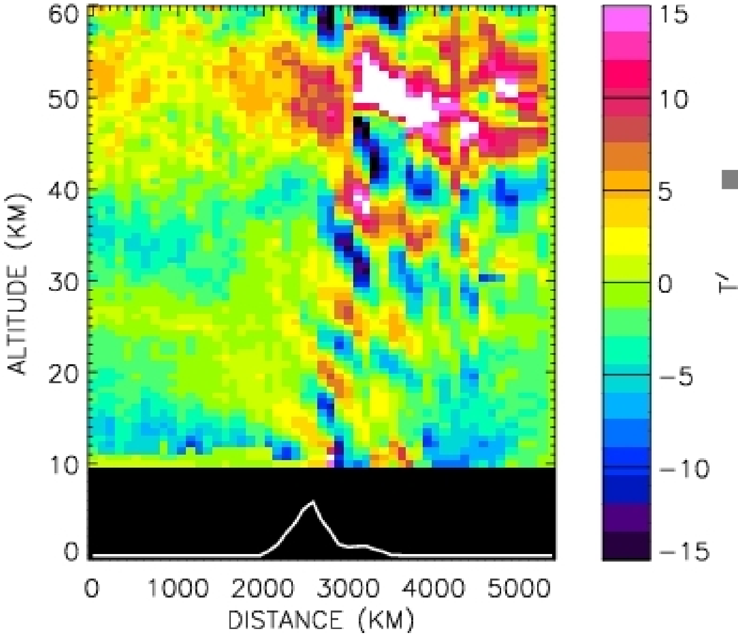
With local values of temperature amplitude $\hat{T}$ and horizontal and vertical wavenumbers (k,m):

$$\boxed{F_M = -(\rho/2)(k/m)\,(g/N)^2\,(\hat{T}\,/\,\overline{T})^2}$$

F_M is a vector with direction given by propagation relative to the wind.
Direction is unknown from limb scanning measurements – a key uncertainty.

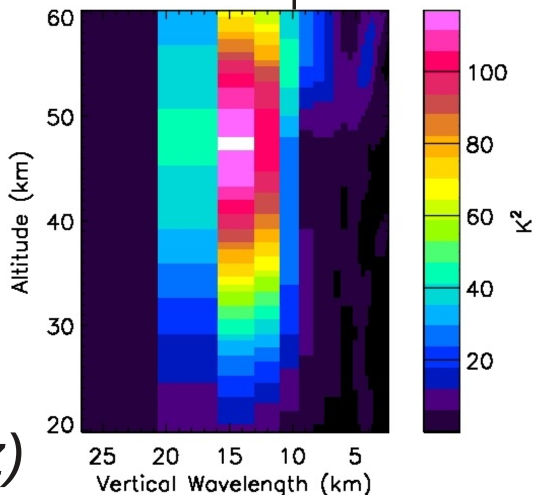
Momentum Fluxes from Limb-Scanning Observations

Alexander et al. [2008] = "**HIRDLS1**"



S-Transform
via cospectrum
of adjacent
T' profiles

Covariance Spectrum



Cospectrum gives $\hat{T}(m,z)$
and phase difference $\Delta\phi$.
Then $k \sim \Delta\phi/\Delta x$.

Ern et al. [2011] = "**HIRDLS2**"

- Another very similar method looks for profile pairs where the maximum amplitude wave in adjacent profiles has approximately the same *m*.
- When *m* does not match, profiles are discarded, retaining ~ half the data.

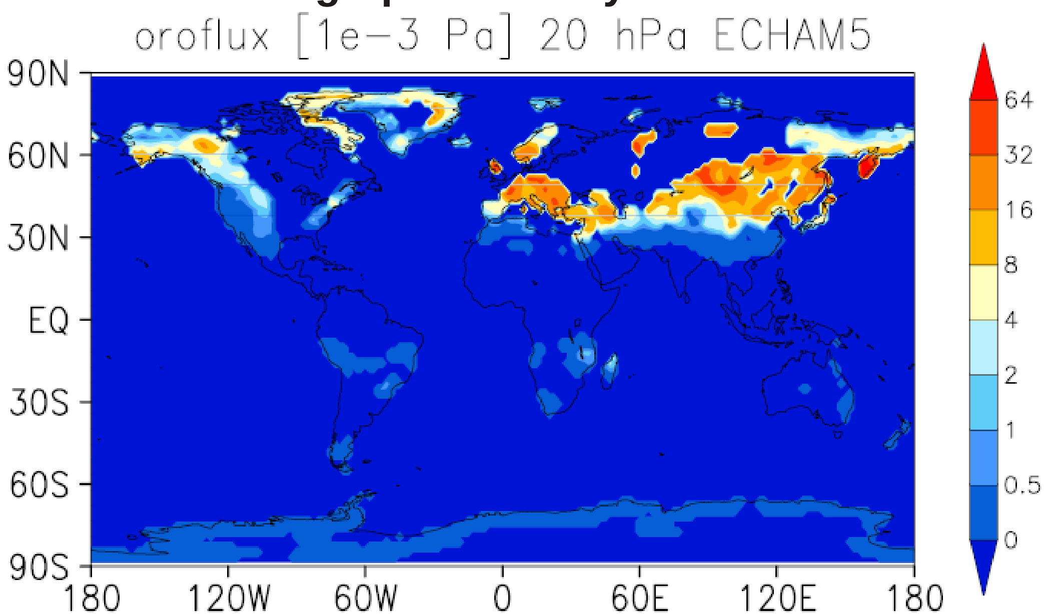
*Where **HIRDLS2** discards profiles, **HIRDLS1** would instead find a weaker wave common to both profiles.*
***SABER** observations are analyzed with the same Ern et al. [2011] method.*

Parameterized Gravity Waves in Climate Models

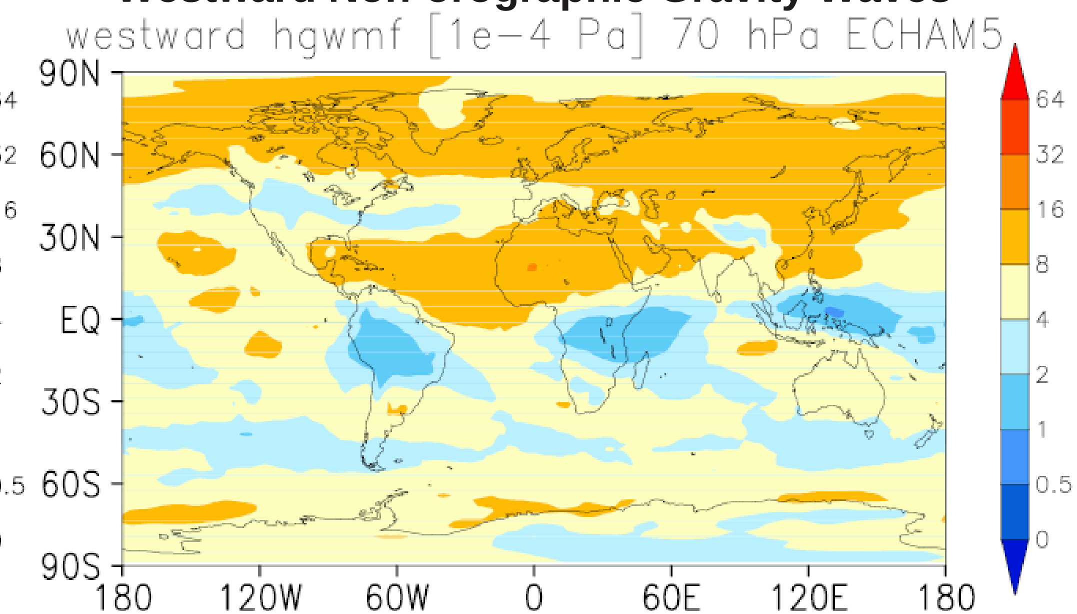
Model	MAECHAM5	HadGEM3	GISS
Resolution	1.875°x1.875°	1.25°x1.875°	2.0°x2.5°
Vertical Levels	95L to 0.01hPa	85L to 84km	40L to 0.1hPa
GW Param:			
Orographic	Lott&Miller 97	Gregory et al 98	McFarlane 87
Non-orographic	Hines 97	Warner&McIntyre 01	Alexander&Dunkerton 99
N.O. Source Level	700hPa uniform	900hPa uniform	100 hPa variable

Example: MAECHAM5 Parameterized Gravity Wave Momentum Flux - January

Orographic Gravity Waves



Westward Non-orographic Gravity Waves



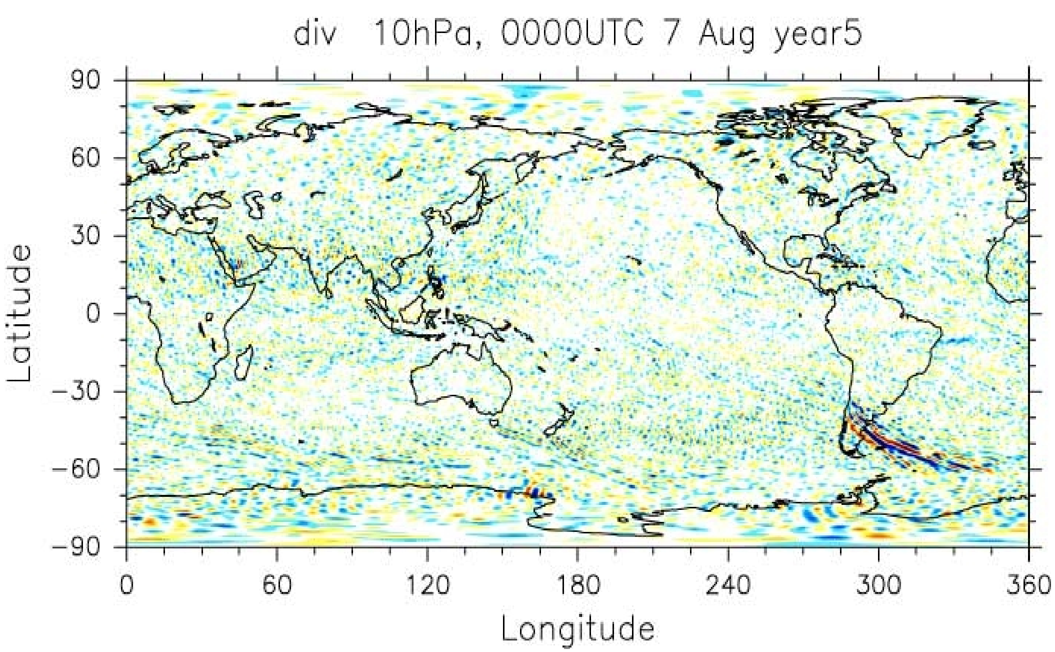
High-Resolution Gravity Wave Resolving Models

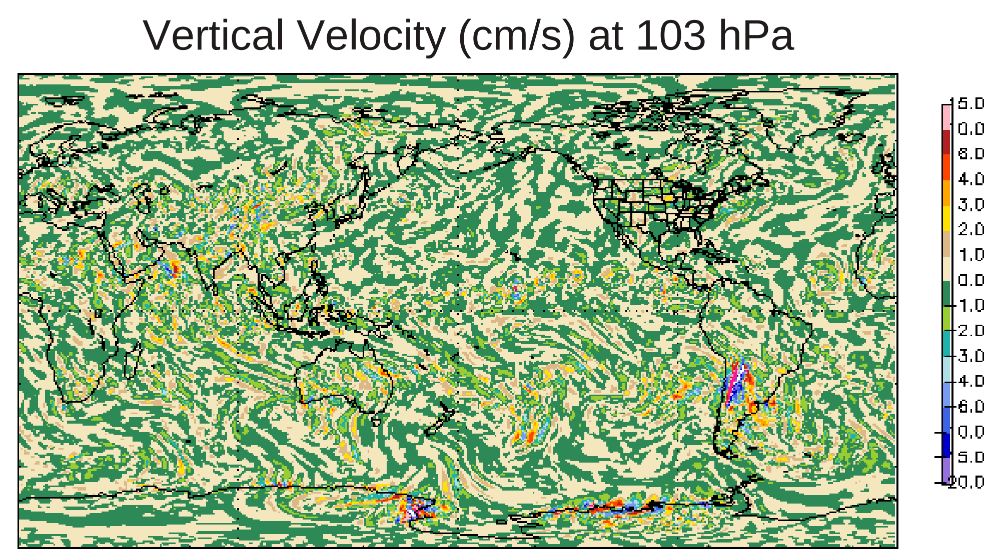
Kanto Model

Spectral model numerics
T213 horizontal resolution ~60km
L256 vertical resolution ~300m to 85km
No parameterized gravity wave drag

CAM5 Model

Finite Volume numerics
0.25^{o} horizontal resolution ~25km
L30 vertical resolution ~2km to 40km)
Parameterized orographic wave drag





Observations

Zonal Means

Two different methods for computing momentum flux from **HIRDLS** (**1**&**2**):

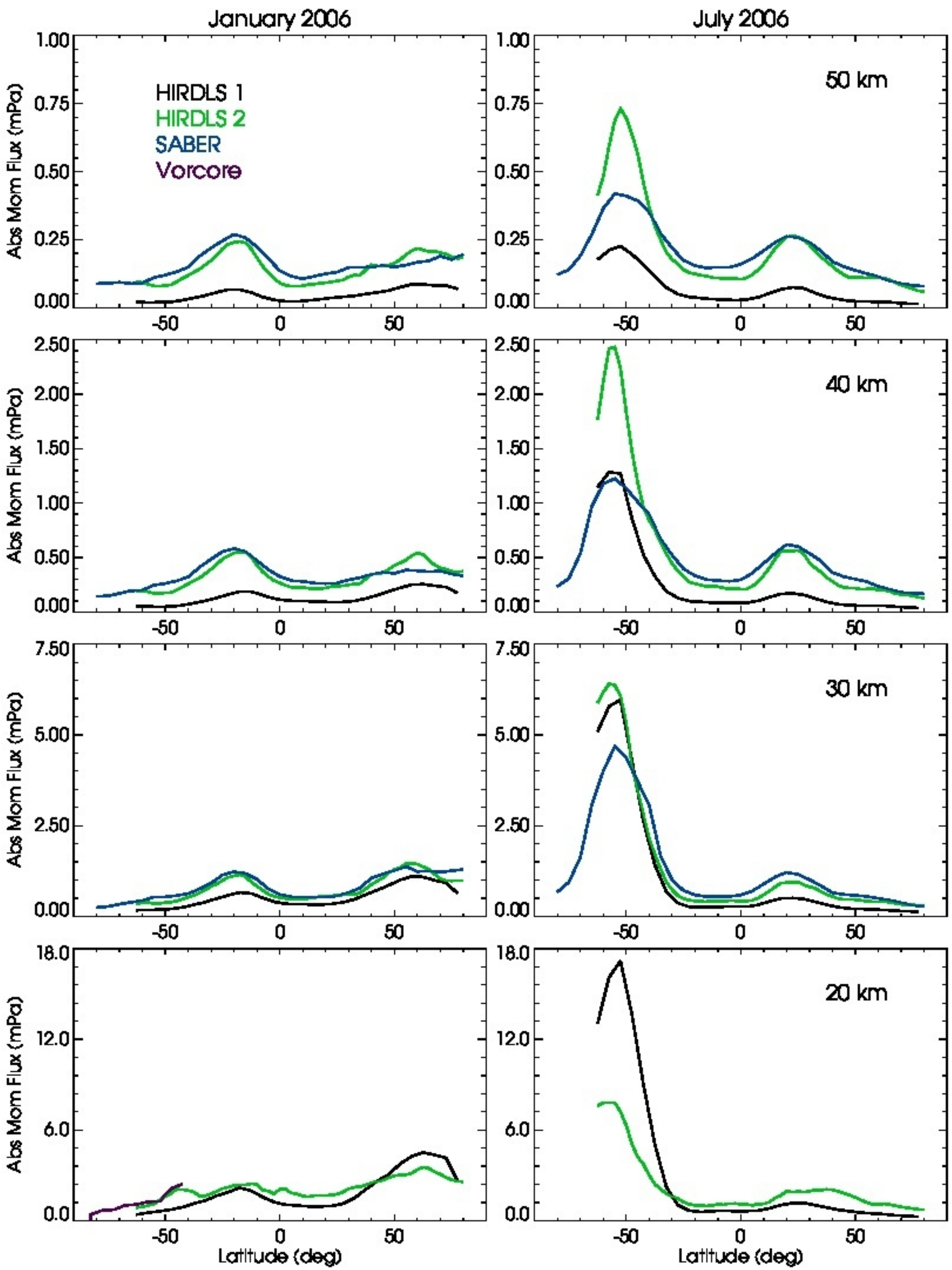
- Alexander et al. [2008]
- Ern et al. [2011]

SABER: limb sounder with same method Ern et al. [2011]

- has ~2x coarser resolution in both the horizontal and vertical
- expect fewer waves resolved
- cannot observe to the lower stratosphere

These differences are only partly understood.

- The differences between HIRDLS**1** and **2** may be mainly due to data rejection criteria.



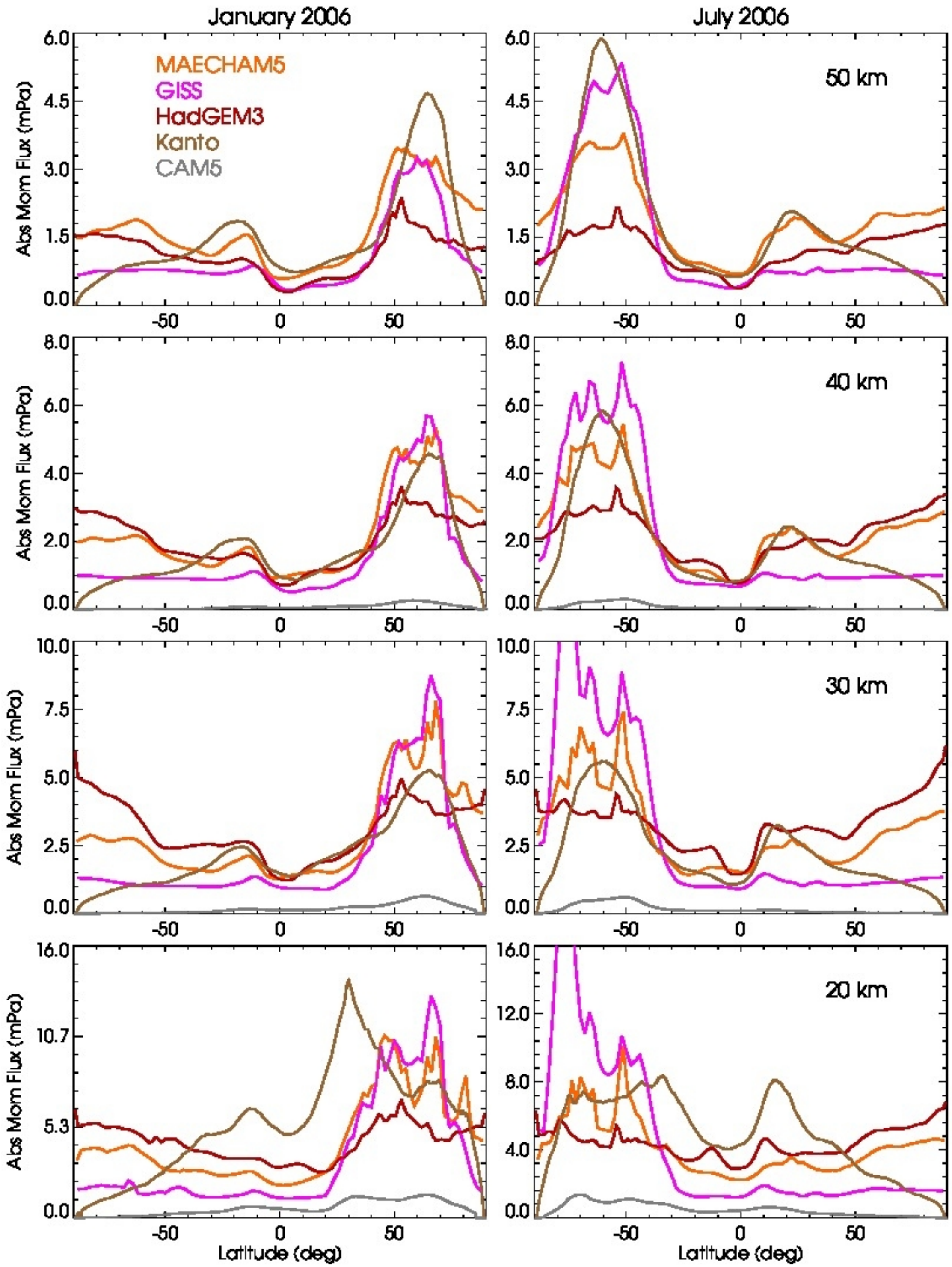
Models

Zonal Means

The three climate models with parameterized gravity waves (**MAECHAM**, **GISS**, **HadGEM**) all look fairly similar.
(Note1: fluxes at the poles do not decrease, but are flat or increase.)

Kanto was designed to have enough gravity wave momentum flux to give a realistic middle atmospheric circulation. Fluxes are similar to parameterizations.

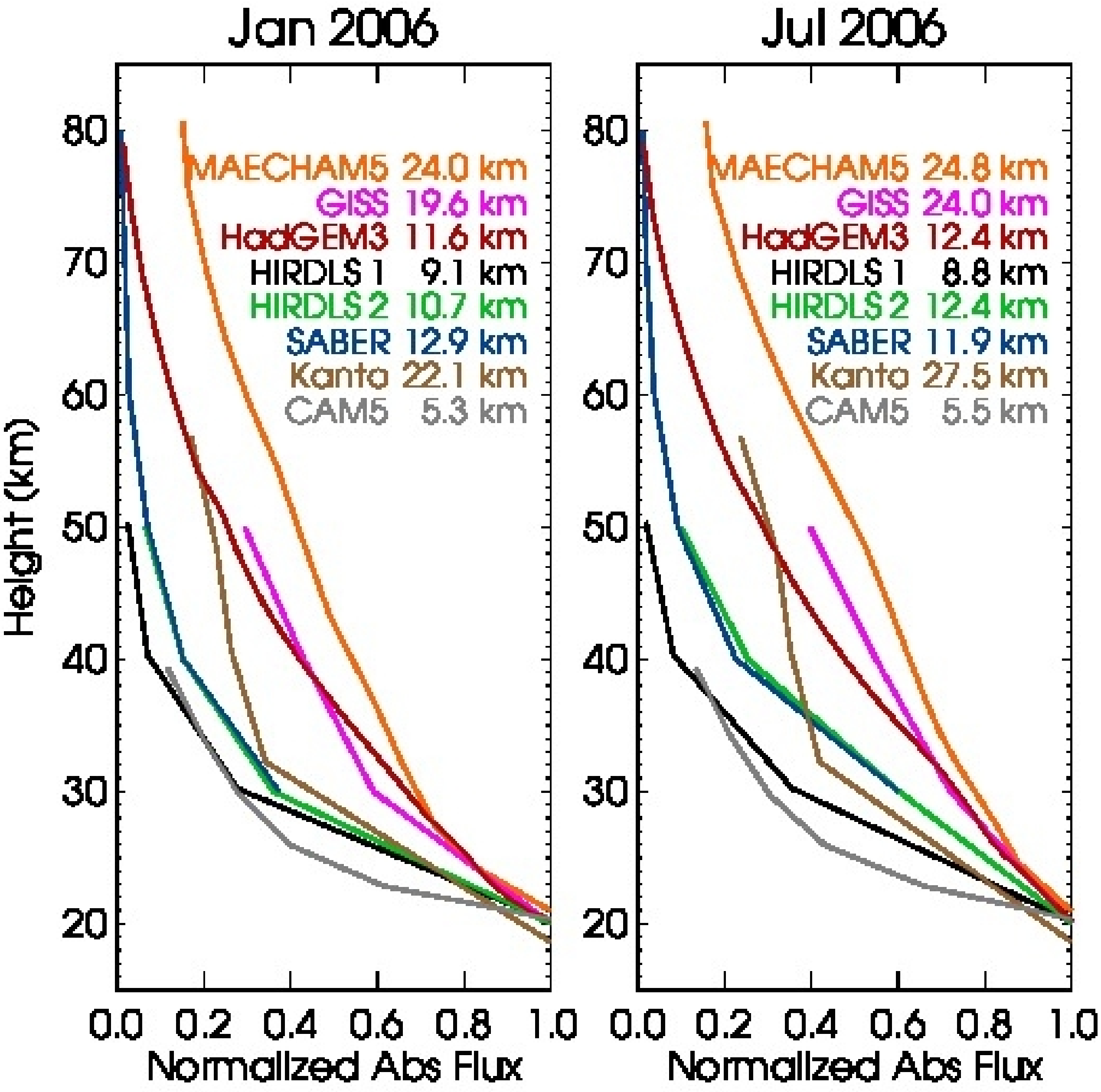
CAM is a traditional climate model run at high resolution. Fluxes are weak because of numerical and explicit dissipation + poor vertical resolution?



Changes w/Altitude

Global Means

- Normalized at 20-km
- Dissipation with height is much stronger for the observations than for the parameterized waves.
- Cause is likely coarse horizontal resolution of the observations, leading to lower breaking levels than the shorter waves that are parameterized.
- CAM5 fast decay likely due to coarse vertical resolution coupled to numerical dissipation.



Global Maps

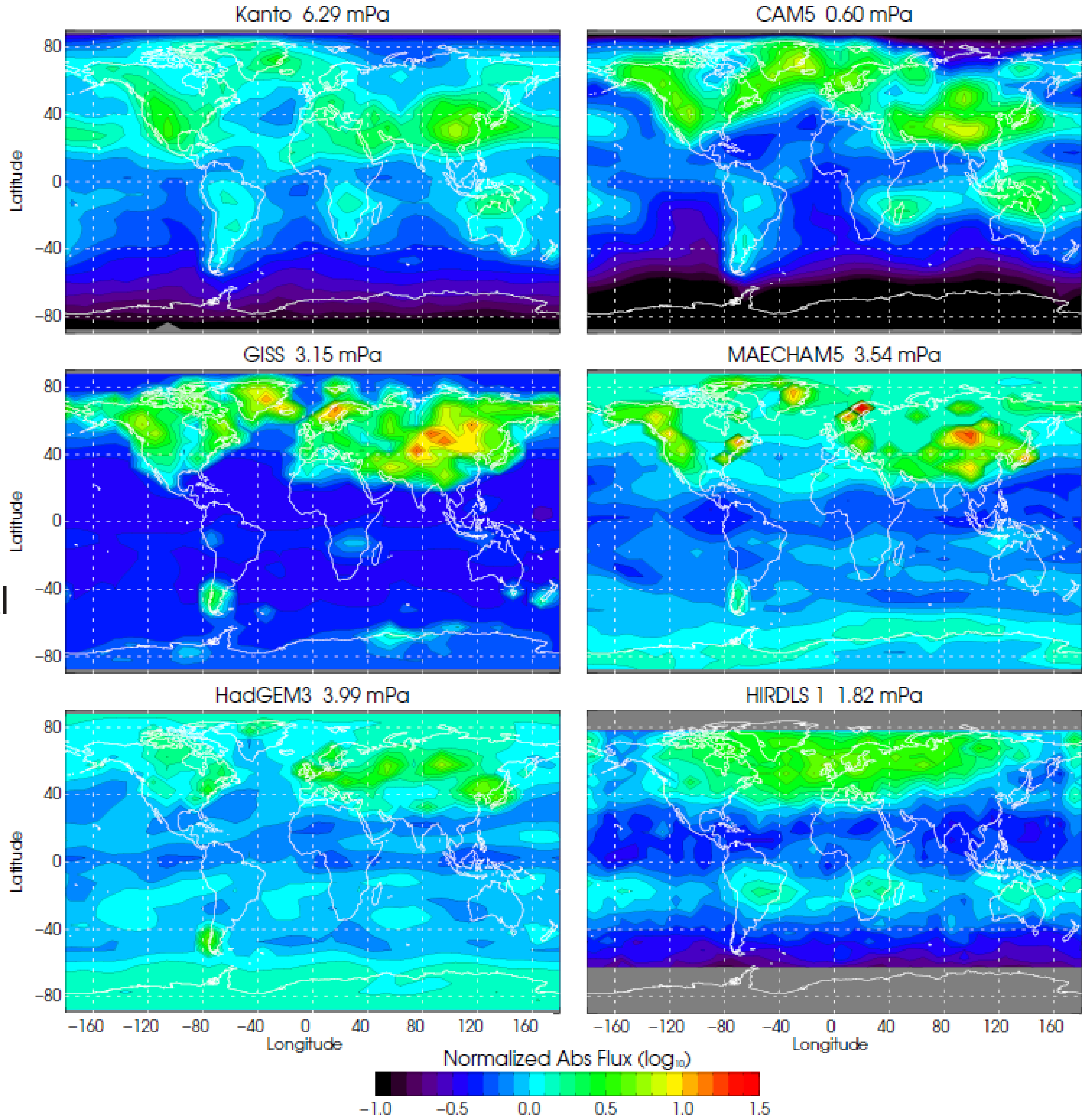
JANUARY
Ratio to
Global Mean
at 20 km

- Similar patterns

- Differences:

Summer subtropical maximum that is weak or absent in parameterizations.

Decay in flux at the poles not present in parameterizations.

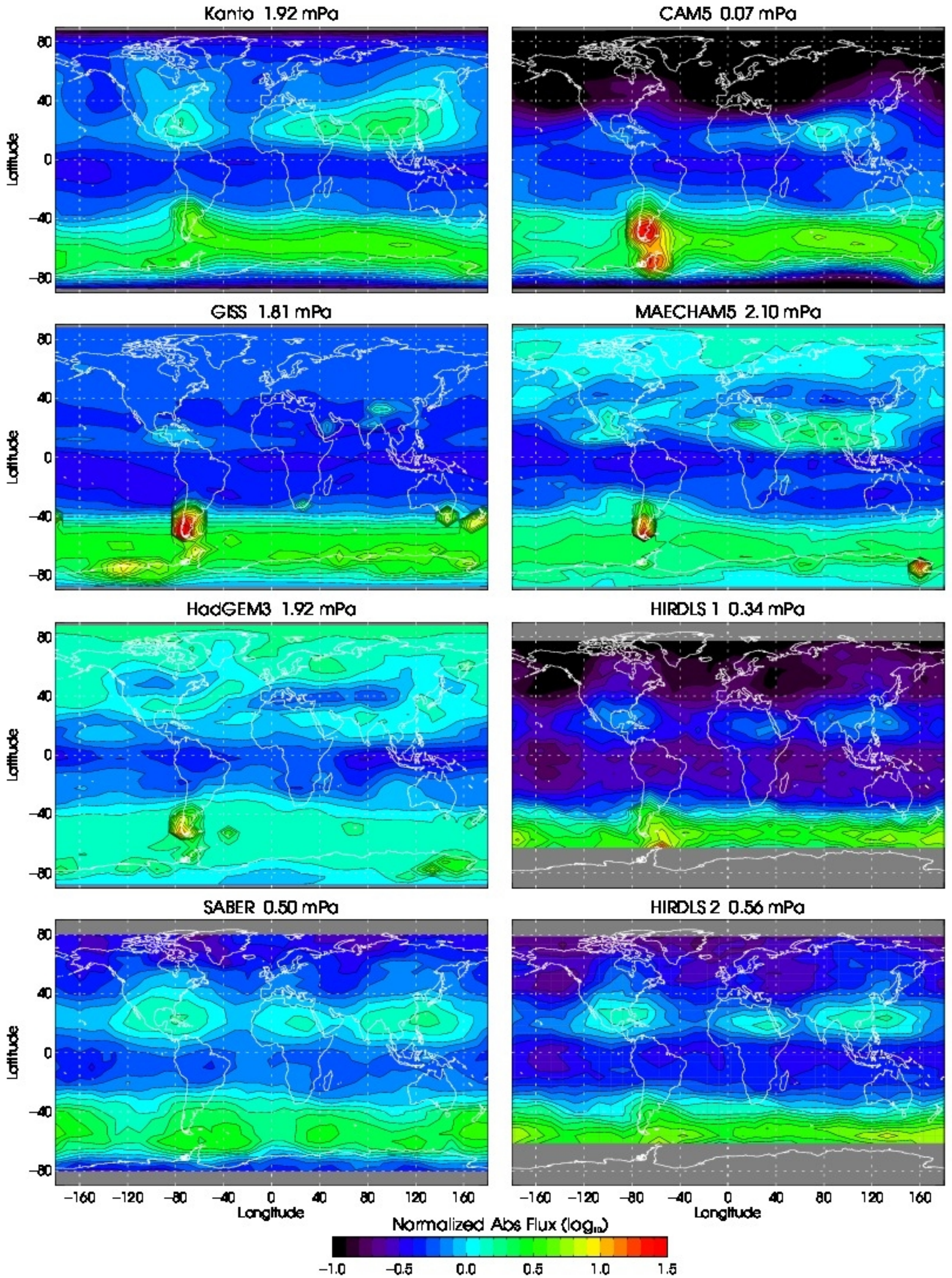


Global Maps

JULY
Ratio to
Global Mean
at 40km

- Parameterizations, high-resolution models, and observations all show enhanced flux above the Asian and N.Am monsoons.

- In the parameterizations, this must be due solely to filtering by the wind.



Summary of Key Results

- Despite using different parameterization methods, **all the models with a middle atmosphere have similar gravity wave momentum fluxes**, presumably because the settings were chosen to obtain a reasonable middle atmospheric circulation and temperature structure.

- Observations and high-resolution models suggest certain geographical variations in momentum flux that do not appear in the parameterizations:
  a. A **rapid decrease in fluxes in summer poleward of 60-70^{o}**
  b. A **peak at summer subtropical latitudes ~20-25^{o}** with localized enhancements over continents.

- **Observations and high-resolution models remain resolution limited**:
  a. Satellite observations are greatly hindered by horizontal resolution .
  b. CAM at 0.25^{o} suffers from lack of vertical resolution, exaggerating wave dissipation with altitude.